5022TA

BELOW-THE-HOOK LIFTING DEVICE
Engineering Note Cover Page

Lifting Device Numbers:

FNAL Site No/ ____________ If applicable

Div. Specific No. 161 If applicable

Asset No. ____________ If applicable

ASME B30.20 Group: (check one)

[X] Group I Structural and Mechanical Lifting Devices
[ ] Group II Vacuum Lifting Devices
[ ] Group III Magnets, Close Proximity Operated
[ ] Group IV Magnets, Remote Operated

Device Name or Description Minerva Frame STrongback

Device was (check all applicable)

[ ] Purchased from a Commercial Lifting Device Manufacturer. Mfg Name ____________
[ ] Designed and Built at Fermilab
[X] Designed by Fermilab and Built by a Vendor. Assy drawing number 3938.300-ME-435758
[ ] Provided by a User or other Laboratory
[ ] Other: Describe ____________

Engineering Note Prepared by James Kilmer Date 2/19/2007

Engineering Note Reviewed by D. Pushka Date 2/20/07

Lifting Device Data:

Capacity 5200 pounds

Fixture Weight 3900 pounds

Service: [X] normal [ ] heavy [ ] severe (refer to B30.20 for definitions)

Duty Cycle ______ 8, 16 or 24 hour rating (applicable to groups III, and IV)

Inspections Frequency BEFORE EACH USE

Rated Load Test by FNAL (if applicable) Date 2/21/2007 Load 6500

[ ] Check if Load Test was by Vendor and attach the certificate

Satisfactory Load Test Witnessed by: John Voirin John VOIRIN 04940N

Signature (of Load Test Witness) John Voirin 04940N

Notes or Special Information:

LOAD TEST 2 WEDGES @ 432 lbs
4 K BLOCKS @ 1410 lbs

6504 lbs

Strongback for Minerva
Jim Kilmer
January 11, 2007

This note describes the engineering calculations for the strongback used to assemble and transport the Minerva detector frames. The heaviest frame that the strongback must support is a heavy target module with the 1.375" steel wedges. That frame weighs approximately 5200 lbs. The strongback must support that weight in two orientations. The frames are built with the strongback horizontal on the floor and in that case much of the load is supported by bending of the long members. When the frame is raised to vertical to prepare for hanging on the support structure then the load reverts to a principally tension load on the long members. See drawings 3938.330_ME-435752 for the parts drawing, -435758 for the weldment drawing, and -444081 for the layout assembly. From the layout it is possible to see that the frame load is almost uniformly distributed on the center of the strongback. See the attached picture of the strongback and a set of wedges positioned on it.

HORIZONTAL LOAD CASE

First look at the horizontal loading case. Note that there are four main beams (items 3 and 21 in drawing 435758). Assume that each beam carries a quarter of the load and that as a worst case that is is a point load in the center. The strongback framing is all made from 12" by 3" by .25" wall structural tubing. The cross beams tie the main beams together and spread the load out carrying the weight to the four main beams. The properties of that tubing are as follows:

$A := 6.63 \cdot in^2$	Cross sectional area
$I_x := 103 \cdot in^4$	Moment of inertia in X-X axis
$S_x := 17.2 \cdot in^3$	Section Modulus in X-X axis
$S_y := 8.73 \cdot in^3$	Section Modulus in Y-Y axis
$r_x := 3.94 \cdot in$	radius of gyration

Model each beam as a simply supported beam with a point load at the center. This would be case 7 on page 2-298 of the AISC code. This case would give the worst moment load on the beams.

$P := \dfrac{5200 \cdot lb}{4}$	Load for each beam is approximately 1/4 of the total
$l := 176.75 \cdot in$	Length of the longest main beam
$Mmax := \dfrac{P \cdot l}{4}$	Mmax is the maximum moment produced
$fb := \dfrac{Mmax}{S_x}$	Bending stress in the beam

$$fb = 3.34 \times 10^{3} \frac{lb}{in^{2}}$$

For structural tubing with an Fy = 46ksi then the allowable bending stress for a lifting fixture would be 33% of the yield or Fb = 15.33 ksi. Since Fb>fb the bending stress is OK.

VERTICAL LOAD CASE

Now look for the tensile stress generated when the frame is being held in a vertical position by the strongback. Once again the four main beam carry the load through the clips (part 17).

$$f_{axial} := \frac{P}{A}$$ Axial stress in main members from frame load

$$f_{axial} = 196.078 \frac{lb}{in^{2}}$$

Tensile stress in the members is also OK because faxial is less that Fb.

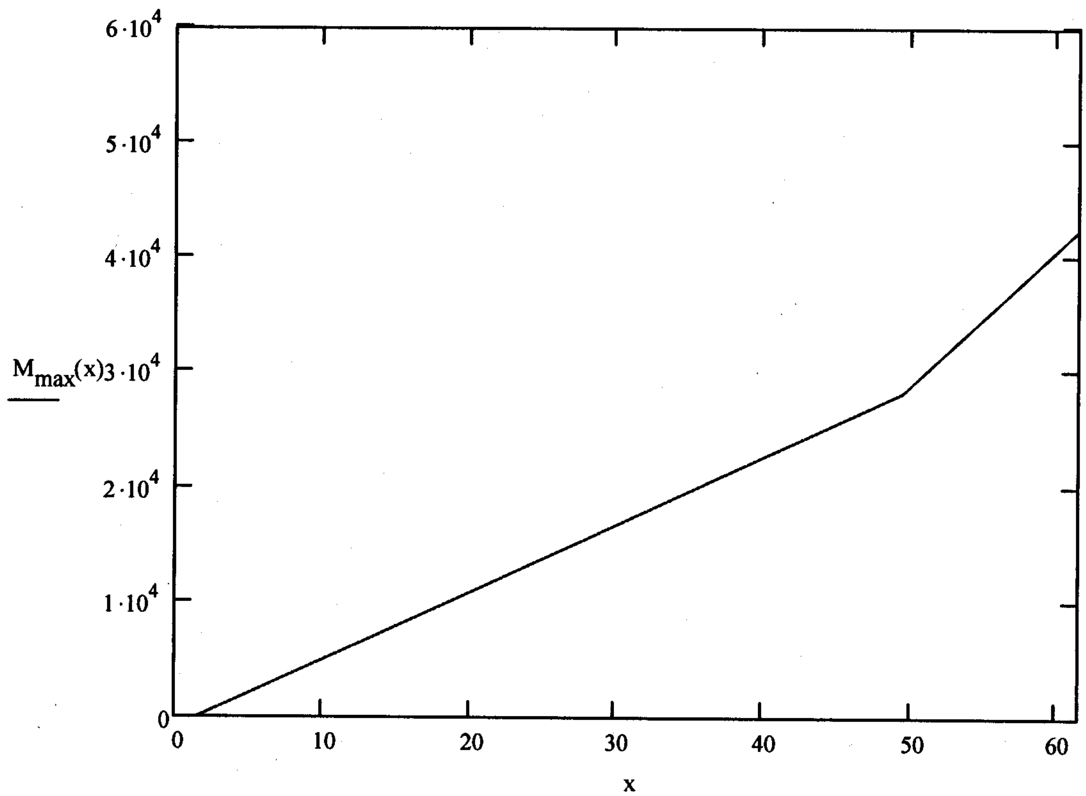
TOP RAIL

Next look at the bending in the upper rail (part 1). Again assuming that 1/4 of the load is carried uniformly on the four main beams split the rail in half and look at one half. See the attached drawing. Study using the sum of two cases of a cantilevered beam, case 21 with P at a = 1.5 inches and with P at a = 48.5 inches, page 2-303 of the AISC code.

$P := \frac{5200 \cdot lb}{4}$	Load on each main member as above
$l := 60 \cdot in$	Center of rail to center of the outer load carrying members
$b := 12 \cdot in$	Center of rail to center of inner load carrying members
$M_{max} := P \cdot l + P \cdot b$	Sum of maximum moment at the center of the top rail half when modelled as a cantilever

First take the above equation and convert it into a function of distance x along the top rail as shown in the case diagram. In the resulting moment function a new function Φ( ) is used. The purpose of this Φ function, called a Heaviside function is to return a value of zero when the number in parenthises is negative. The result is that with only using the distance x a piecewise function can be generated. On the next page is the resulting moment as a function of distance along the beam.

$M_{max}(x) := \Phi(x - 1.5) \cdot P \cdot (x - 1.5) + \Phi(x - 49.5) \cdot P \cdot (x - 49.5)$

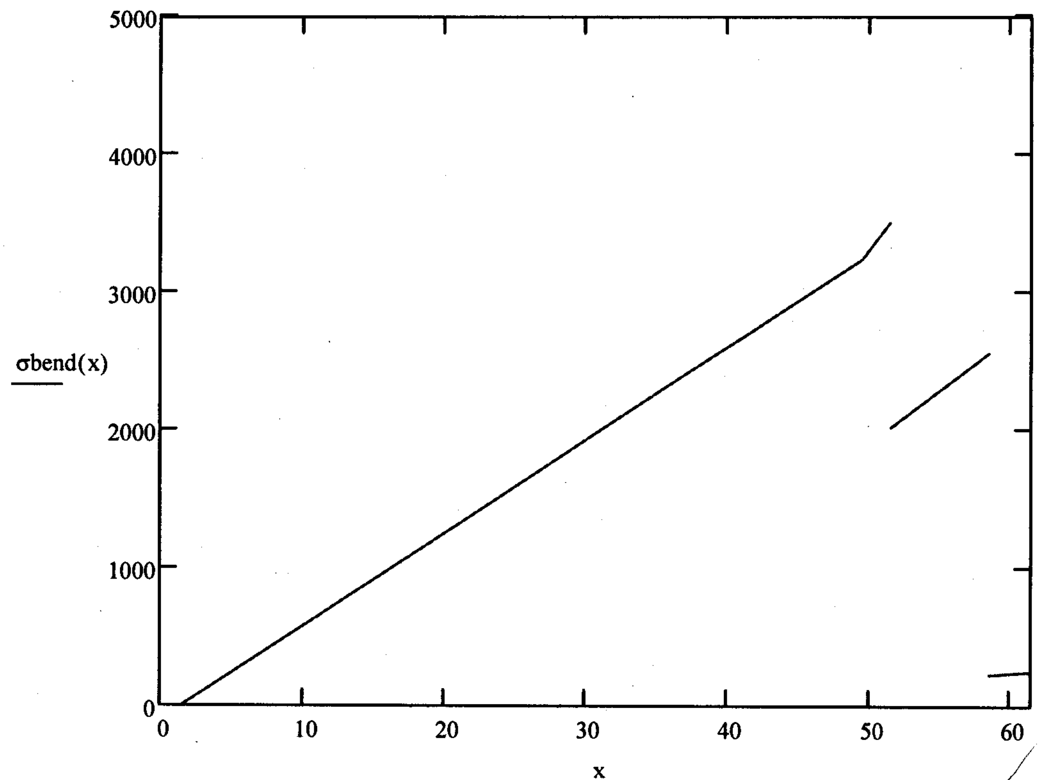


This moment diagram is the result of summing two forces on the beam at different x values, where x is the distance along the beam starting from zero at the free end. The first is 1300 lbs at 60 inches from the center of the beam and the second is 1300 lbs at 12 inches from the center. The attached spreadsheet shows the calculations for the composite Section Modulus Sy at each section of the top rail where the lifting attachment is welded to the rail. The same Heaviside function is used to produce a function for the beam of Sy as a function of x. The following graph shows the resulting bending stress along the beam.

$M_{MAX} \approx 4.3 \times 10^4$ IN-LBS

$\sigma = \frac{M}{S_y} = \frac{(4.3 \times 10^4 \text{ IN-LBS})}{8.73 \text{ IN}^3} = 4925$ psi

$$\sigma bend(x) := \frac{M_{max}(x)}{8.73\cdot\Phi(x-1.5)+(15.2-8.73)\cdot\Phi(x-51.5)+(178.4-15.2-8.73)\cdot\Phi(x-58.5)}$$



Maximum shear on the rail occurs between the center of the rail and the inner vertical rail. The shear stress is as follows.

$V := 2\cdot P$ Shear force on the rail tube in the center

$$\sigma_{shear} := \frac{V}{A}$$

$\sigma_{shear} = 392.157 \frac{lb}{in^2}$ This shear stress for a 12" by 3" by .25" wall tube is OK.

Since the bending stress is well below the 15.3 Ksi allowable for the structural tubing and the shear stress is far less this upper rail is OK

TUBING WELDS

Next calculate the stress on the rail welds. All of the welds attaching the 12" by 3" by .25" tubing are 5/16"fillet welds completely around the circumference of the tubes. The welds were done using E70XX welds with a yeild of 70 Ksi yield strength. Calculate the shear area on any weld.

$t_{weld} := \frac{5}{16 \cdot \sqrt{2}} \cdot in$ This is the weld throat distance. .3125 × .707

$L_{weld} := 2 \cdot 12 \cdot in + 2 \cdot 3 \cdot in$ This is the length of the weld around the circumference. ✓

$A_{weld} := t_{weld} \cdot L_{weld}$

$A_{weld} = 6.629\, in^2$ ✓

The largest force either in tension or in shear for any given tube connection is one quarter of the maximum frame load or 1300 pounds.

$\sigma := \frac{1300 \cdot lb}{A_{weld}}$ ✓

$\sigma = 196.104 \frac{lb}{in^2}$ ✓

This stress for either the shear force on the welds from a horizontal load or a tension stress when the load is vertical is OK in either case. The allowable stress for such welds would be 1/3 of yield or 23.3 Ksi which is factors larger.

BOTTOM FRAME CLIPS

The frame plates are supported on the strongback when in a vertical position bypart number 17. Those parts are welded to the tubing rails by 3/8 inch welds on the three lower sides. Although there are six of these parts assume that only the four on the main vertical rails take all of the load. Find the shear stress in these welds. See the attached picture.

$t_w := \frac{3}{8 \cdot \sqrt{2}} \cdot in$ Weld throat

$L_w := 3.5 \cdot in + 3.0 \cdot in + 5.0 \cdot in$

$A_w := t_w \cdot L_w$

$A_w = 3.049\,in^2$

Each of these four main support plates would then support 1300 pounds in shear on the welds.

$$\sigma supportshear := \frac{1300 \cdot lb}{A_w}$$

$$\sigma supportshear = 426.314\,\frac{lb}{in^2}$$

This shear load is also well below the allowable stress of 23.3Ksi for an E70XX weld.

The bolts holding the caps on the support plates are four 1/2" - 13 UNC socket head cap screws. Notice that these bolts do not take the 1300 pound load in shear. They only hold the frame wedges on the strongback. Socket head cap screws are typically the equivalent of grade 8 bolts, but for this note assume that they are no better than grade two bolts (equivalent to A307) with an allowable tensile stress of 20.0 Ksi, see AISC page 4-3). Calculate the allowable tensile load on the bolts.

$$A_{bolt} := \frac{3.1415}{4} \cdot (0.5 \cdot in)^2$$

$$P_{bolt} := A_{bolt} \cdot 20 \cdot 10^3 \cdot \frac{lb}{in^2}$$

$$P_{bolt} = 3.927 \times 10^3\,lb$$

Thus the cap on any given plate support being held on with four screws are each being clamped with a force of almost 16,000 pounds which is more that the weight of a completed frame. The bolts are OK for the bottom cap plates.

TOP FRAME CLIPS

The frames are held to the strongback at the top by clips made out of angle iron machined to fit in the designed space between hanging frames. The clamp brackets are bolted to the strongback through steel plates welded to the structural tubing. These brackets are used to hold the frames onto the strongback when the strongback is raised to the vertical position. The mounting plates are welded to the tubing by two 4" long welds that are 3/8" fillets using E70XX rod. Assume that each of the four clamps must share the load or support 1300 lbs. See the attached picture.

$T_w := \frac{3}{8\cdot\sqrt{2}}\cdot in$ Throat distance of a 3/8" fillet weld

$A_w := T_w\cdot(2\cdot4\cdot in)$

$A_w = 2.121\,in^2$ Weld stress area

$\sigma_{weld} := \frac{1300\cdot lb}{A_w}$

$\sigma_{weld} = 612.826\,\frac{lb}{in^2}$ Shear stress on the weld.

This stress is well below the 23.3 Ksi allowable for the E70XX weld so the drilled boss plate is attached OK.

The bolts must be checked next. There are four 1/2" - 13 UNC bolts holding each clamp bracket. Use the allowable shear table on page 4-5 of the AISC. For these bolts use the small print at the bottom.

$F_u := 10000\cdot\frac{lb}{in^2}$ Assume A307 bolts

$F_v := 0.17\cdot F_u$ This is the allowable shear stress for threads in the shear plane

$F_{shearbolt} := F_v\cdot A_{bolt}$

$F_{shearbolt} = 333.784\,lb$ This is the allowable for each bolt and there are four bolts.

$F_{total} := F_{shearbolt}\cdot 4$

$F_{total} = 1.335\times10^3\,lb$

Since Ftotal is greater than 1300lb the bolts are adequate in shear. Also we have assumes the poorest grade of bolts made.

The last part of the upper clamps to check is the clamp bracket itself (MB-444124). Model it as a simple cantilevered beam as in case 21 of the AISC code, page 2-303. Each of the four clamps must hold one quarter of the weight of a frame or 1300 lbs.

$b := 4.0\cdot in$

$h := 0.75 \cdot in$

Choose the h at the place of maximum bending moment at the root of the cantilever

$$I_x := \frac{b \cdot h^3}{12}$$

$$I_x = 0.141\ in^4$$

$$M_{peak} := 1300 \cdot lb \cdot 1.5 \cdot in$$

$$\sigma clampbend := \frac{M_{peak} \cdot \left(\frac{.25 \cdot in}{2}\right)}{I_x}$$

$$\sigma clampbend = 1.733 \times 10^3 \frac{lb}{in^2}$$

This bending stress is less than 1/3 of the yeild strength of A36 steel so the part is OK.

WELDING CLAMPS

The strongback is also used as a flat platen to fixture up the frames as flat as possible before and during welding. While the strongback is horizontal on the floor the six wedges are loaded on and aligned in position. Then clamps are used to hold the six wedges on the strongback as shown in ME-444081. The six wedges are welded at the inside and outside corners only and then the strongback is raised to vertical and hung on the welding fixture. The frame is now vertical and can be worked on from both front and back. The distortion can be managed by working back and forth on each of the welds until the frame is complete. The strongback is lowered and left to cool before the welding clamps are taken off to try and keep it straight. The clamps are made from double UNISTRUT and bolted to blocks welded to the strongback tubing. These blocks are welded with two 1/4" weld three inches long on either side of the block. The welds are in shear. See the attached picture.

$$t_{weld} := \frac{.25 \cdot in}{\sqrt{2}}$$

$$L_{weld} := 2 \cdot 3 \cdot in$$

$$A_{weld} := t_{weld} \cdot L_{weld}$$

The load on each block is one quarter of the weight of a wedge. Each heavy (1.625" thick) wedge is 475 lbs.

$$\sigma_{weld} := \frac{475 \cdot lb}{A_{weld}}$$

$$\sigma_{weld} = 447.834 \frac{lb}{in^2}$$

The blocks are welded on with E70XX rod so these welds are fine.

The clamp UNISTRUT is held on with a 1/2" - 13 UNC threaded rod. Therefore a 250 pound load is on each rod at 0.196 square inch or a stress of 1275 psi. These welding clamps are used only long enough to get the frames welded up. Then they are removed and not used again.

STRONGBACK LIFTING ATTACHMENT

The strongback lifting attachment is shown in drawing Mc-444331. The strongback lifting attachment is bolted to the top lifting tube by six A325 bolts with the shear plane throught the threads. These bolts are 3/4" - 10 UNC. From the table of allowable shear loads on bolts for a bearing type connection wth threads in the shear plane thse bolts are rated for 9.3 kips per bolt or nearly 56 kips which is over five times the total load of 9300 lbs for the frame and strongback. Hence the bolts are OK. The lifting attachment is welded together with four 12" long by 1/2" fillet welds. See the attached picture.

$$t_{weld} := \frac{0.5 \cdot in}{\sqrt{2}}$$ weld throat distance

$$L_{weld} := 12 \cdot in \cdot 4$$

$$Aweld := t_{weld} \cdot L_{weld}$$

$$Aweld = 16.971\ in^2$$

$$\sigma weld := \frac{9300 \cdot lb}{Aweld}$$

$$\sigma weld = 548.008 \frac{lb}{in^2}$$

This weld stress is far below the allowable stress for a lifting fixture using E70XX rod of 23.3 Ksi.

Now revisit the bolts and the side plates. The pick point on the fixture is not in the center of the fixture. To decide how the load is distributed on the six bolts call the two bolts farthest from the pick point the pivots for the load. Also assume that the bolts share the load equally.by summing moments find the load on the bolts.

$9300 \cdot lb \cdot 9 \cdot in = 8.37 \times 10^4 \, in \cdot lb$

$$boltshear := \frac{8.37 \cdot 10^4 \cdot in \cdot lb}{2 \cdot 6 \cdot in + 2 \cdot 3 \cdot in}$$

$boltshear = 4.65 \times 10^3 \, lb$

The bolts are still fine with this level of shear on each of them. This load is also seen by the side plates as a tear-out force. The side plates are.75" thick and the holes are 1" from the edge.

$$bearingstress := \frac{boltshear}{.75 \cdot in \cdot .75 \cdot in}$$

$bearingstress = 8.267 \times 10^3 \frac{lb}{in^2}$ This stress is below the allowable stress for A-36 steel in a lifting fixture of 12Ksi.

$$tearoutstress := \frac{boltshear}{.75 \cdot in \cdot 1 \cdot in}$$

$tearoutstress = 6.2 \times 10^3 \frac{lb}{in^2}$ This tearout stress is also OK for an A-36 steel plate.

HANGING ANGLE OF FIXTURE

During the prototyping and assembly of the Minos planes using a strongback it was determined that it was very important that the strongback never hang exactly plumb. It must have a slight angle of 1 degree or greater so that the plane was always "on top of the strongback" even when the fixture was vertical. In the attachedspreadsheet the distance from the back of the strongback was calculated for each of the frame types. The distance of the heaviest loads was almost 10 inches from the back. In order to make sure that the angle was kept the lifting attachment has it's pick point set for 12 inches from the back of the strongback. The center of mass for the system is roughly at the center of the strongback. The frames are all centered on the strongback and the strongback is almost symetric in the vertical plane.

$H := \frac{176.75 \cdot in}{2} + 10 \cdot in + 4.5 \cdot in$ Center of Mass to pick point distance

$d := 2 \cdot in$ distance difference from pickpoint to CM

$$\Theta := \operatorname{atan}\left(\frac{d}{H}\right)$$

$$\Theta = 1.114\,deg$$

This shows that for the heaviest frame load the strongback will have the requisite 1 degree angle. Lighter loads will have larger angles.

Strongback top rail calculations

Part	Cross section area	Iyy	d	Ad^2	Iyy (displaced)
For the section throught the center of the upper rail where lifting tube (part 9) is					
12" by 3" tube	6.63 IN^2	11.1 in^4	0	0	11.1 in^4
12" by 6" tube	16.4 in^2	287 in^4	7.5 in	922.5 in^4	1209.5 in^4
				I total =	1220.6 in^4
For the section where theL6 X 4 X 3/8 angle is (model as 3/8" thick plate)					
3/8" plate	4.5 in^2	0.0527 in^4	1.687 in	12.81 in^4	12.87 in^4
12" by 3" tube	6.63 IN^2	11.1 in^4	0	0	11.1 in^4
				I total	23.97 in^4

Minerva Plane weights

Table is for 1.25" thick wedges. All weights in pounds.

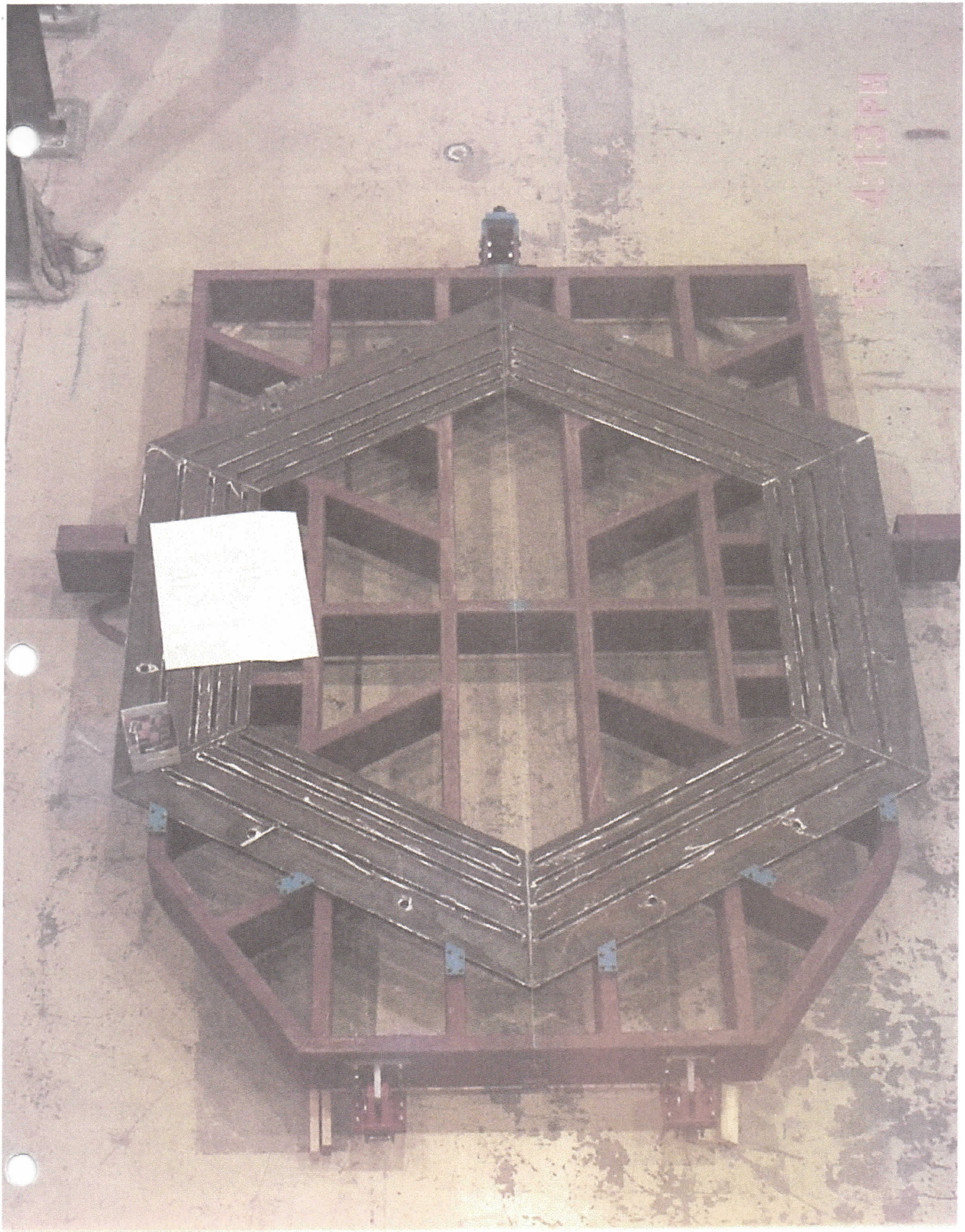
Plane Type	Frame weight	Lead	Misc.	Ears	Steel absorber	Total weight	X1	Strongback wt	X2	Xbar
Normal ux or vx plane (active)	2570	99	100	63.5	0	2832.5	12.625	3700	6	8.872608
Heavy target module (FE and Pb)	2570	883	200	63.5	1189	4905.5	12.625	3700	6	9.776531
Downstream ECAL	2570	377	100	63.5	0	3110.5	12.625	3700	6	9.025778
Downstream HCAL	2570	0	200	63.5	1801.25	4634.75	12.625	3700	6	9.684

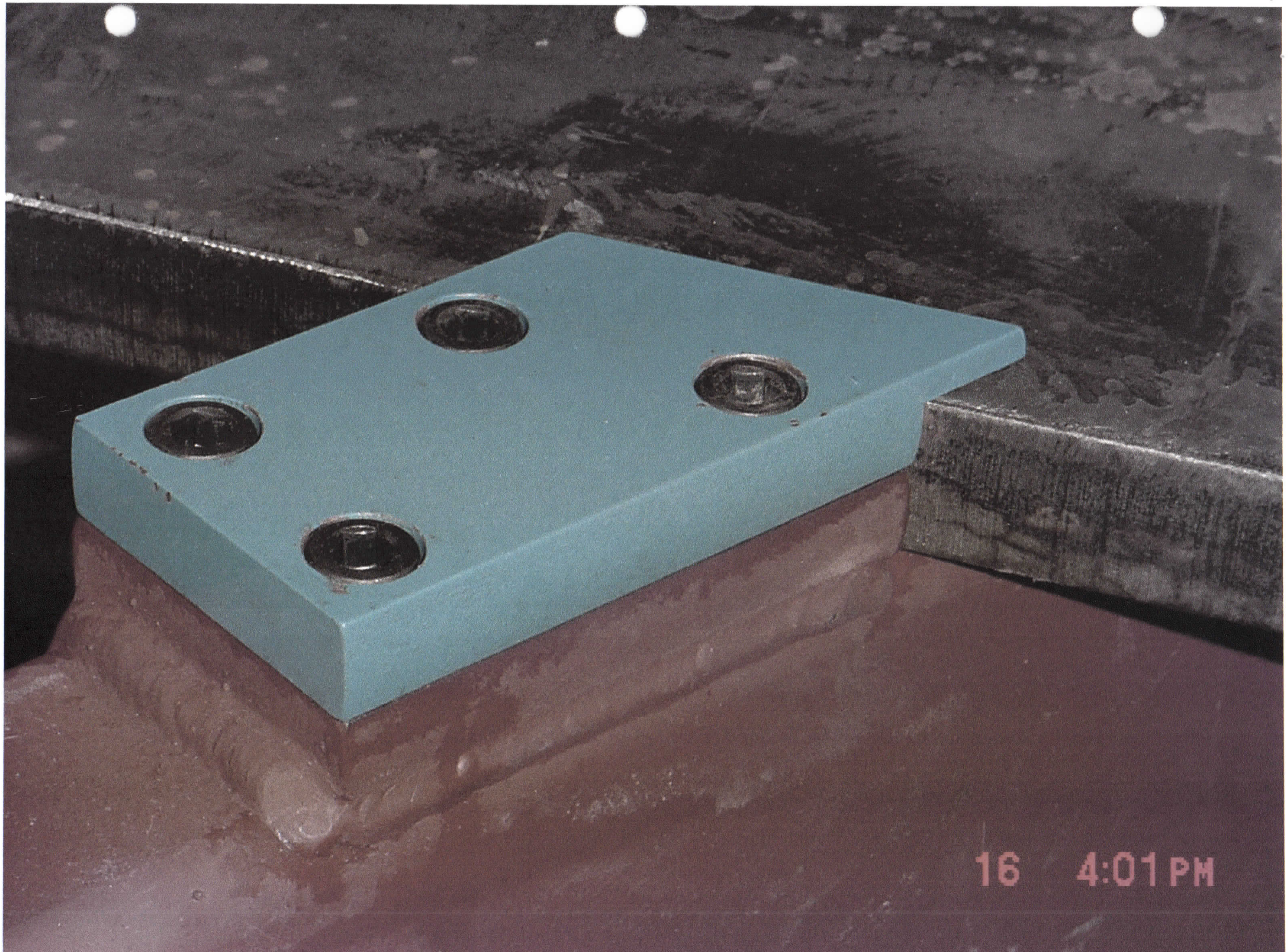
Change wedges to 1.375" thick.

Normal ux or vx plane (active)	2827	99	100	63.5	0	3089.5	12.69	3700	6	9.044223
Heavy target module (FE and Pb)	2827	883	200	63.5	1189	5162.5	12.69	3700	6	9.896996
Downstream ECAL	2827	377	100	63.5	0	3367.5	12.69	3700	6	9.18763
Downstream HCAL	2827	0	200	63.5	1801.25	4891.75	12.69	3700	6	9.80898

RSF calc'd WGTS:

SECTION	WGT
VETO WALL ASS'Y	20115 spread over 24"
USHCAL	3054
USECAL	3054
AT	3152
DSECAL	3471
DSHCAL	4636
HEX FRAME w/ ears, 1.25" THK	2748

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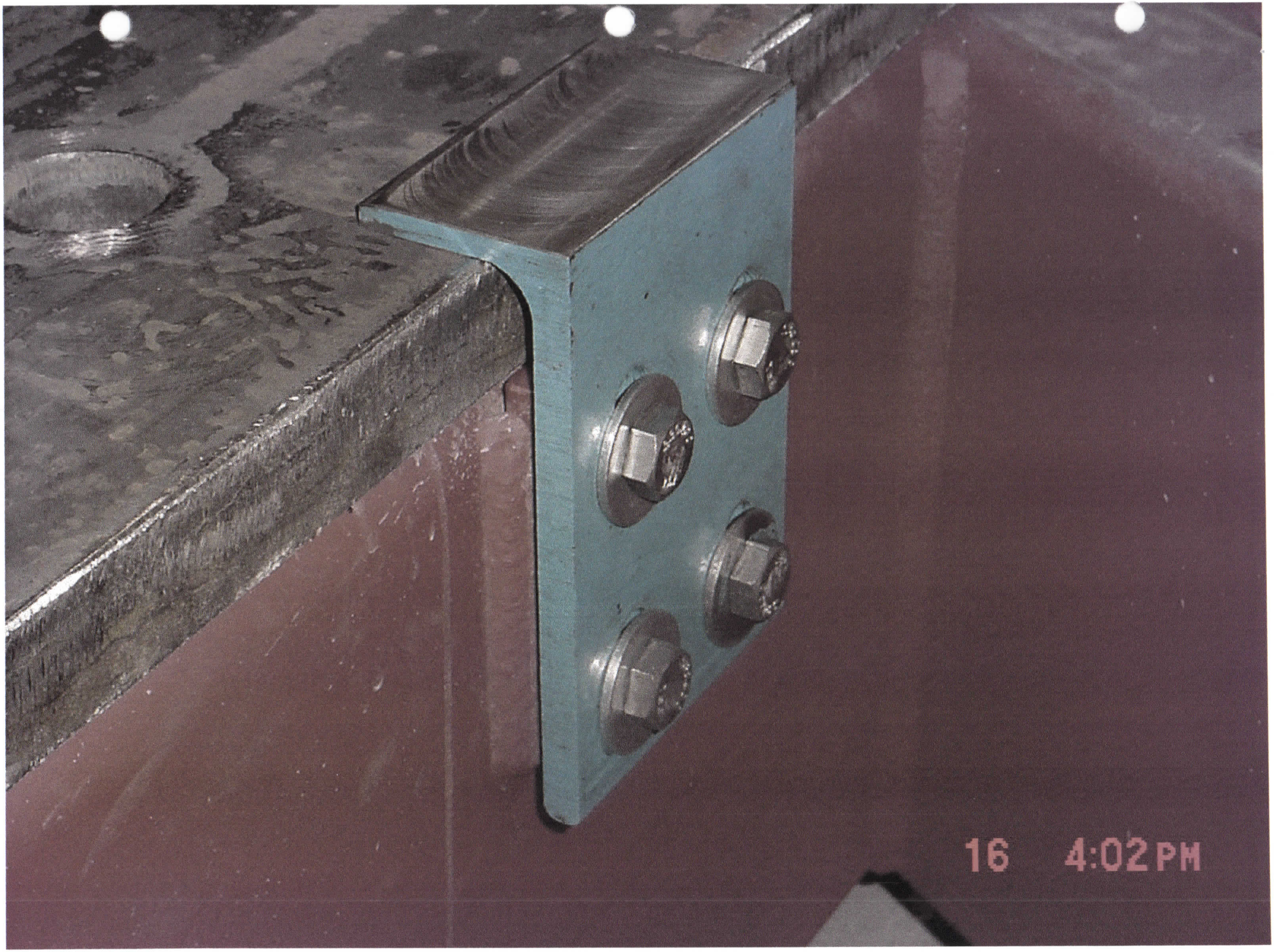
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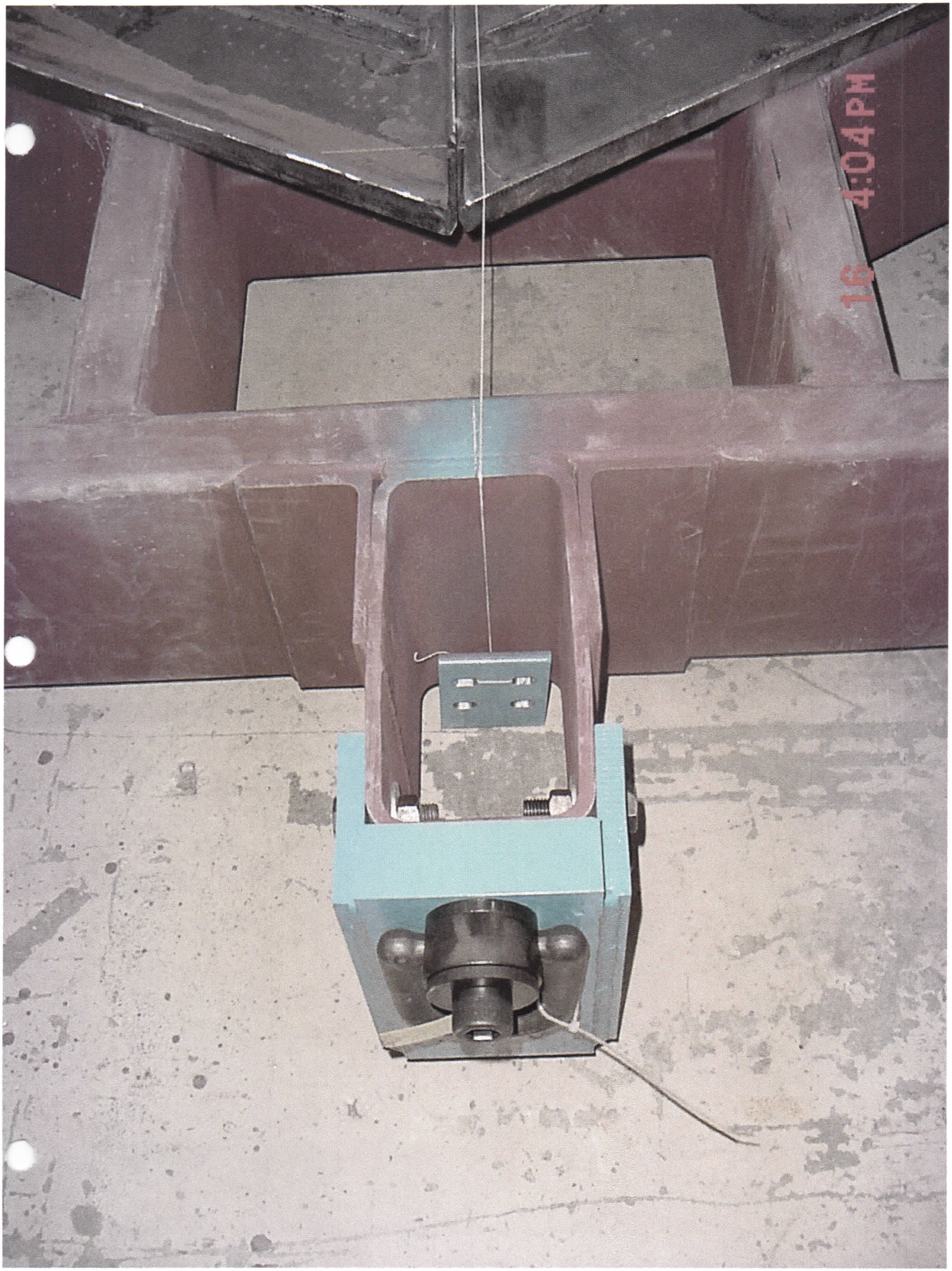
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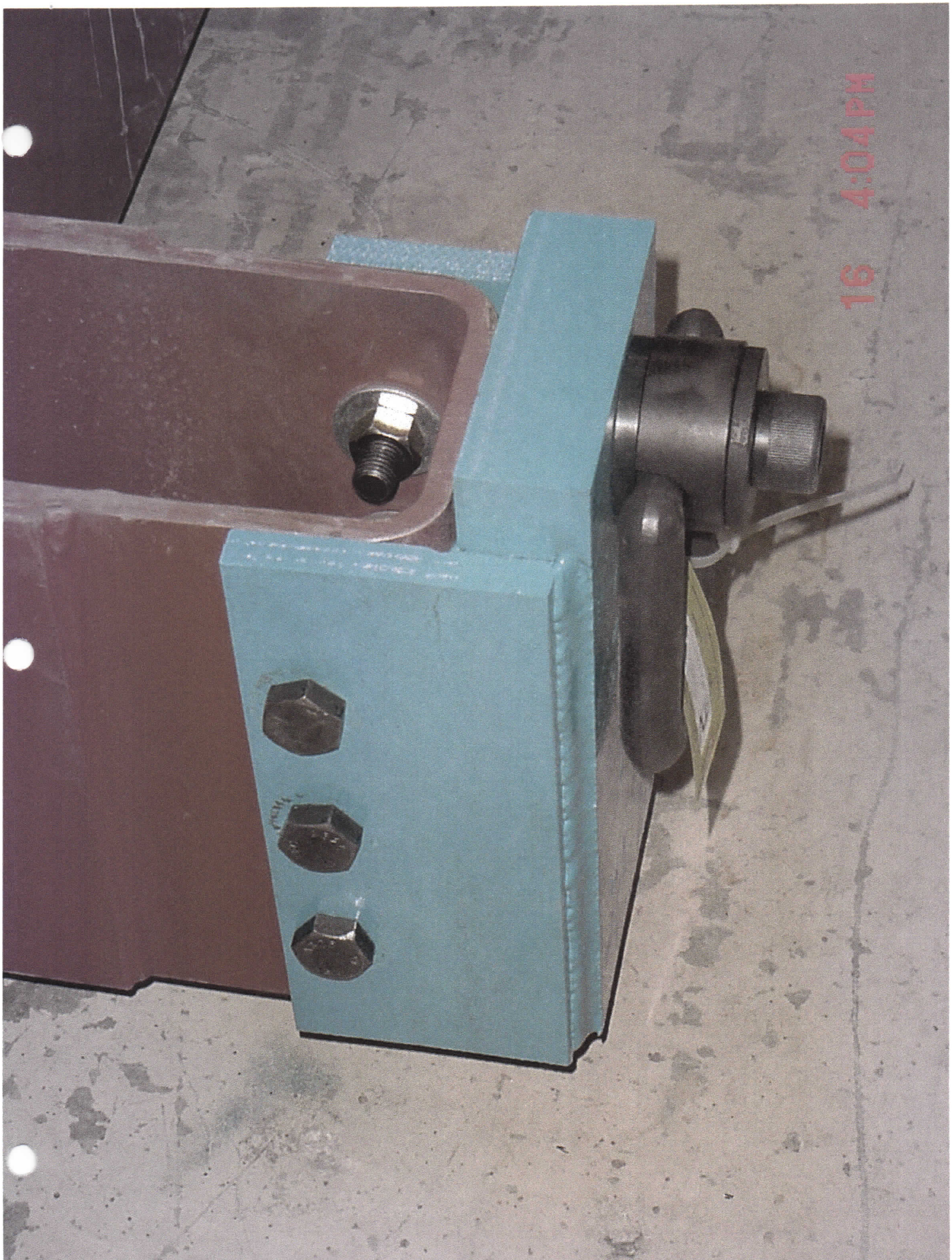
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WEAR EYE
PROTECTION
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miller